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FEDERAL COMMUNICATIONS COMMISSION
OFFICE OF THE SECRETARY

**Via Hand Delivery**
Ms. Marlene H. Dortch
Secretary
Federal Communications Commission
445 12th Street, SW
Washington, D.C. 20554

**Re: Mobile Satellite Ventures Subsidiary LLC**
***Ex Parte* Presentation**
**IB Docket No. 01-185;**
**File No. SAT-ASG-20010302-00017 et al.**

Dear Ms. Dortch:

Mobile Satellite Ventures Subsidiary LLC ("MSV") hereby files an original and four (4) copies of the attached papers for inclusion in the record of the above-captioned proceedings.

The above-captioned application proceeding has been designated as "permit-but-disclose" with respect to MSV's request to launch and operate a next-generation mobile-satellite service system. *See* Report No. SPB-170 (June 26, 2001).

Very truly yours,

David S. Konczal

cc: Paul Locke

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# OUT-DOOR MEASUREMENTS AND ANALYTICAL PREDICTIONS OF CROSS-POLARIZATION ISOLATION


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## INTRODUCTION

MSV has performed outdoor measurements of the cross-polarization isolation from a left-hand circularly polarized (LHCP) transmit antenna to a right-hand circularly polarized (RHCP) Mobile Terminal (MT) receiving antenna. Figure 1 shows a block diagram of the test set-up. Two helical transmit antennas, one using RHCP and the other LHCP, were set up on the MSV building roof overlooking the building parking lot. The two antennas were identical except for polarization sense, with a peak gain of 11.5 dBi. As illustrated below, the antennas were connected to distinct signal generators providing low-level C. W. carriers with 10 kHz frequency separation. The antennas were mounted on a camera tripod to provide accurate azimuth and elevation pointing. Figure 2 is a picture of the transmitter configuration.

**Figure 1: Test Configuration Block Diagram (Overhead View)**

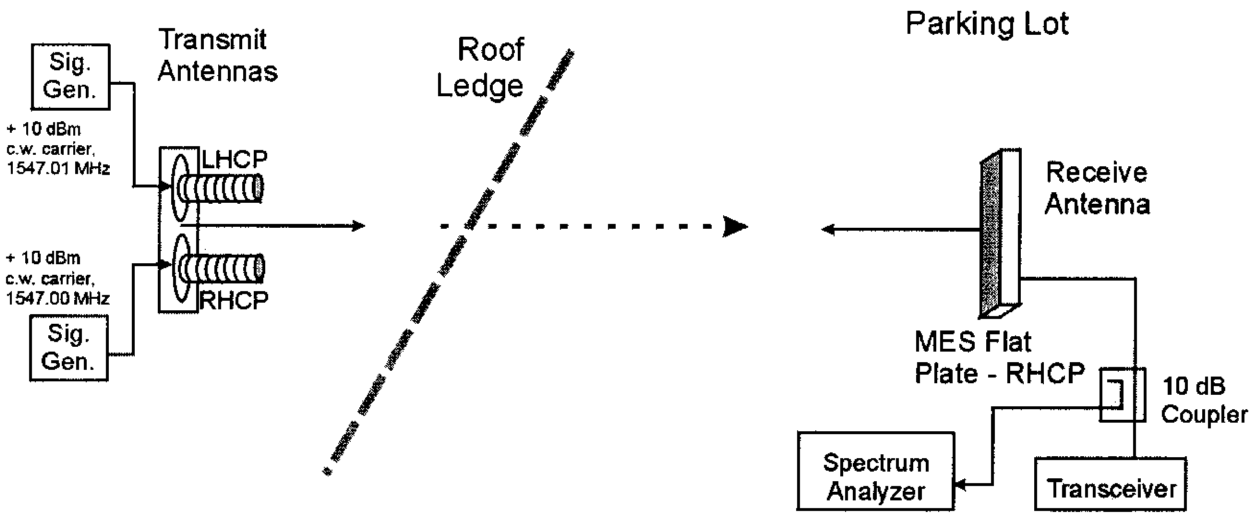



**Figure 2: Transmit Antenna Configuration on Roof**

On the ground, an Inmarsat Mini-M terminal flat lid RHCP antenna was used to receive the transmitted carriers. An RF coupler placed between the antenna unit and the terminal transceiver provided a test point for connecting a spectrum analyzer to measure the received signal levels from the antenna.

Three locations near the MSV building were used to place the receive antenna for gathering data. Location #1 was beyond the parking lot in a grassy area very close to route 267, about 200 feet from the transmit antennas. Location #2 was a small grassy island between two parking areas roughly 120 feet from the transmit antennas. Location #2 was much closer to parked vehicles than Location #1 (location #1 was close to moving vehicles). Location #3 was also in a parking lot about 425 feet from the transmitting antennas. A row of trees blocked direct line-of-sight from the roof transmit antennas to Location #3. There were several cars parked proximate to Location #3, the closest being about 30 feet from the receive antenna. Table 1 summarizes the parameters/characteristics for each of the three receiver antenna locations.

**Table 1: Receive Antenna Locations**

| Location # | Distance from Transmit Antennas | Comments |
|---|---|---|
| 1 | ~200 ft. | Area close to moving vehicles (Route 267) |
| 2 | ~120 ft. | Area close to stationary vehicles |
| 3 | ~425 ft. | Area blocked from direct line-of-sight by trees and also close to parked vehicles |

As shown in Figure 1, both transmit and receive antennas were oriented directly toward each other in azimuth. However, the transmit antennas were pointed at a 5-degree down-tilt to simulate a typical base station antenna orientation. The MT receive antenna was pointed at a 40-degree up-tilt as may be the case for receiving an Inmarsat satellite in some regions. For location #3, a second set of measurements was performed with the receive antenna at $30^{o}$ elevation to represent more northerly locations.

With the antenna orientations described above, the levels of the LHCP and RHCP signals at the receive antenna were measured on the spectrum analyzer. Given that the gain patterns of the two transmit antennas were the same, the difference in received levels between the RHCP and LHCP signals, as measured at the RHCP receive antenna, is attributed to the cross-polarization isolation between the LHCP transmit antenna and RHCP receive antenna.

## MEASUREMENTS

Table 2 shows the measured cross-polarization isolation for Locations #1, #2, and #3. Two measurements were taken at each location, denoted "A" and "B", at different times of the day.

**Table 2: Cross-Polarization Isolation Measurements (dB)**

| Location | Measurement "A" | Measurement "B" | dB-Average |
|---|---|---|---|
| **#1** | 11.7 | 10.8 | **11.25** |
| **#2** | 12.0 | 12.5 | **12.25** |
| **#3 - 30° pointing elev.** | 8.8 | 10.8 | **9.8** |
| **#3 - 40° pointing elev.** | 8.3 | 11.4 | **9.85** |
| | | **dB-Average Over All Locations :** | **10.79** |

Based on the above measurements, the average cross-polarization isolation is 10.8 dB, averaged over all 3 locations. The minimum measured isolation was 8.3 dB and it occurred at the distance of 425 feet (~ 130 meters) from the transmit antenna.

**Discussion:** In theory, two ideal oppositely polarized antennas will exhibit infinite polarization isolation in a non-fading environment. In the real outdoor environment, polarization isolation can be degraded by the presence of RF reflections due to the local surroundings, and by imperfect polarization purity of the antennas.

Polarization purity can be determined from an antenna's voltage axial ratio, which is 0 dB for an ideal circularly polarized antenna. Deviations from pure circular polarization (CP) lead to elliptical antenna characteristics with associated axial ratios greater than 0 dB. On the other extreme, an ideal linearly polarized (LP) antenna has an infinite axial ratio. Thus, any antenna can be characterized as being elliptically polarized, with CP and LP being limiting cases. In Appendix A, a general formula is derived for calculating the polarization mismatch loss between two arbitrary elliptically polarized antennas. This formula is given in equation (25) of Appendix A.

As stated earlier, in the outdoor measurements conducted by MSV the transmitter and receiver antennas were aligned toward each other in azimuth but their elevation pointing differed. The transmit antennas were pointed at a 5° down-tilt to simulate a base station geometry. The receiving antenna was pointed at 30° or 40° elevation, thus placing the transmit antenna bore-sight substantially on the fringes of the receive antenna main lobe. Thus, some degradation in the polarization performance of the receive antenna toward the transmit antennas was anticipated.

Based on the above, we estimated the transmit antennas and receive antenna axial ratios toward each other to be 1 dB and 3 dB, respectively. Appendix A equation (25) was then used to predict a polarization isolation of between 8 dB and 14 dB, depending on the orientation of the ellipse major axes of the two antennas. (The polarization isolation referred to here is simply the negative of the isolation loss given in equation (25).) The average polarization isolation values measured (shown in Table 2) fall within the range predicted by the analysis of the Appendix.

In general, the polarization isolation will become smaller as the transmitting and receiving antennas depart from being co-linear in azimuth. However, for such situations the additional isolation that will be provided by the antenna gain discrimination will compensate for any loss in polarization isolation.

Mobile Satellite Ventures LLC

# Appendix A

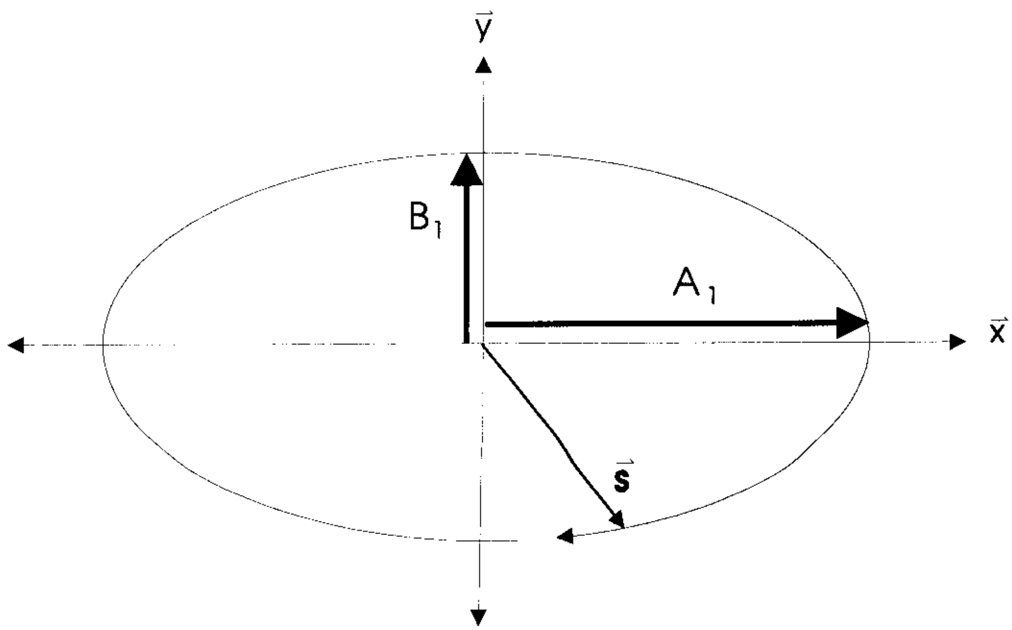
## Polarization Mismatch Loss between Two Elliptically Polarized Antennas

By:
Gary Churan, MSV

**Introduction:**
In this paper, a general formula is derived for calculating the polarization mismatch loss (also called coupling efficiency) between two elliptically polarized antennas. The input parameters for the calculation are the axial ratios of the two antennas, the polarization sense, and the angle between the major axes of the two antennas. The formula can be extended to treat linear polarization (by setting the axial ratio to a very large number) or circular polarization (axial ratio =1), which are just limiting cases of elliptical polarization. Following the derivation, polarization mismatch losses are calculated for a few specific cases of interest.

**Analysis:**
Consider 2 elliptically polarized antennas, denoted antenna #1 and antenna #2, which are defined by their polarization sense and axial ratios $r_1$ and $r_2$. Antenna #1 transmits a right-hand circularly polarized C.W. carrier, s(t), toward receive antenna #2. The voltage vector of s(t) is depicted in Figure 1, where the direction of propagation is into the page.

**Figure 1: Transmitted Signal s(t) From Antenna #1**



The voltage vector **s** rotates in a clockwise direction along the ellipse shown in Figure 1. $A_1$ is the peak magnitude along the major axis (x-axis) and $B_1$ is the peak magnitude along the minor axis (y-axis). The axial ratio is defined as the ratio of the voltage along the major axis to the voltage along the minor axis. For antenna #1, the axial ratio $r_1$ is:

$$r_1 = A_1 / B_1 \qquad (1 \le r_1 \le \infty) \tag{1}$$

The signal s(t) can be expressed as the sum of perpendicular vector components along the major and minor axes as follows:

$$s(t) = A_1 \sin(\omega t + \varphi)\underline{\underline{\mathbf{x}}} + B_1 \cos(\omega t + \varphi)\underline{\underline{\mathbf{y}}} \qquad \text{(right-hand sense)} \tag{2}$$

where $\omega$ is the carrier frequency, $\varphi$ is an arbitrary phase constant, and $\underline{\underline{\mathbf{x}}}$ and $\underline{\underline{\mathbf{y}}}$ indicate the vector directions along the major and minor axes, respectively.

To facilitate the development that follows, we now require that the time-averaged power of s(t) be equal to 1 for any choice of $r_1$. Let Ps denote the time-averaged power of s(t). Then:

$$Ps = \lim_{T \to \infty} 1/T \int_{-T/2}^{T/2} s^2(t)\, dt = \lim_{T \to \infty} 1/T \int_{-T/2}^{T/2} [A_1^2 \sin^2(\omega t + \varphi) + B_1^2 \cos^2(\omega t + \varphi)]\, dt$$

$$= [A_1^2 + B_1^2]/2 = 1. \tag{3}$$

Using equations (1) and (3), the magnitudes $A_1$ and $B_1$ can now be expressed in terms of the antenna axial ratio as follows:

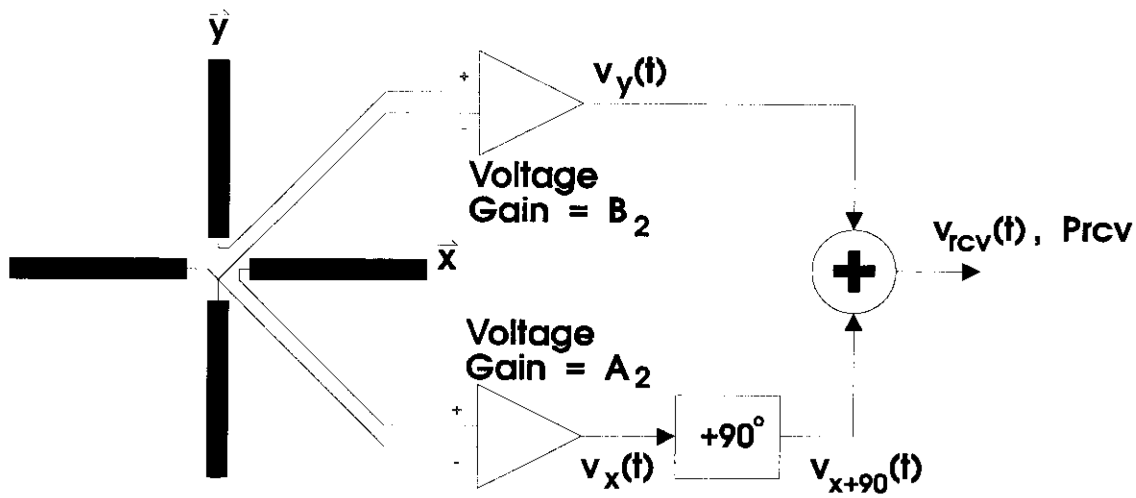
$$A_1 = r_1 [2/(r_1^2 + 1)]^{1/2} \tag{4}$$

$$B_1 = [2/(r_1^2 + 1)]^{1/2} \tag{5}$$

The elliptically polarized receive antenna #2 is shown in Figure 2. It consists of two identical linearly polarized elements perpendicularly oriented along the major axis (x-axis) and minor axis (y-axis) of the ellipse. The received voltages from the two elements are amplified by gain constants $A_2$ (major axis) and $B_2$ (minor axis), to produce output voltage signals $v_x(t)$ and $v_y(t)$, respectively. The signal $v_x(t)$ is then phase shifted by +90° to produce $v_{x+90}(t)$. The +90° phase shift gives the antenna a right-hand polarization sense. Finally, the antenna output signal $v_{rcv}(t)$ is given by:

$$v_{rcv}(t) = v_{x+90}(t) + v_y(t). \tag{6}$$

**Figure 2: Receive Antenna #2 Block Diagram**




The axial ratio $r_2$ for this antenna is defined by the ratio of the voltage response in the major axis to the voltage response in the minor axis, which are in turn set by the gains $A_2$ and $B_2$, respectively:

$$r_2 = A_2/B_2 \qquad (1 \le r_2 \le \infty) \tag{7}$$

We now impose a second requirement, that the gain of receive antenna #2 remain constant at unity gain regardless of the value selected for $r_2$. That is, the antenna output signal power (Prcv in Figure 2) must equal the signal input power Ps when the transmitter and receiver polarizations are identically matched. For this condition to hold, the squared voltage gains for the two orthogonal antenna elements must sum to 1. Thus:

$$\text{Antenna Gain} = A_2^2 + B_2^2 = 1. \tag{8}$$

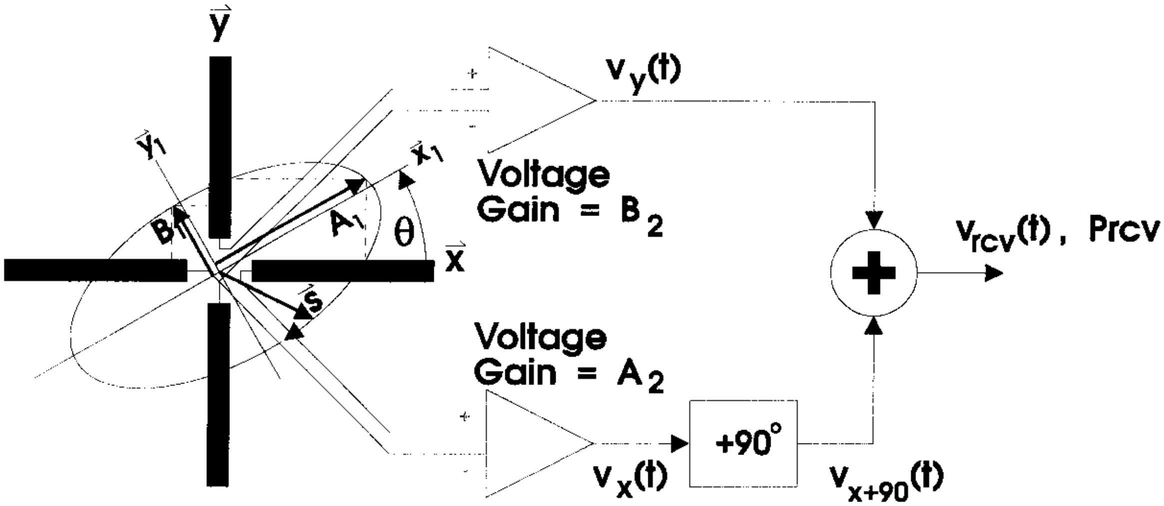
Equations (7) and (8) lead to the following expressions for $A_2$ and $B_2$ in terms of antenna axial ratio $r_2$:

$$A_2 = r_2 / (r_2^2 + 1)^{1/2} \tag{9}$$

$$B_2 = 1/(r_2^2 + 1)^{1/2} \tag{10}$$

Figure 3 illustrates the transmitted signal s(t) voltage vector which is now superimposed on the receive antenna. The angle between the major axes of the transmitter and receiver antennas is denoted $\theta$.

**Figure 3: Transmitted Signal Orientation Relative to Receive Antenna**




Recalling the expression for s(t) in equation (2), and given the angle $\theta$ between the transmit and receive major axes, the following expressions are derived for $v_x(t)$ and $v_y(t)$:

$$v_x(t) = A_2\left[A_1\cos(\theta)\sin(\omega t+\varphi) - B_1\sin(\theta)\cos(\omega t+\varphi)\right] \qquad (11)$$

$$v_y(t) = B_2\left[A_1\sin(\theta)\sin(\omega t+\varphi) + B_1\cos(\theta)\cos(\omega t+\varphi)\right] \qquad (12)$$

Phase shifting of $v_x(t)$ by +90° yields:

$$\begin{aligned} v_{x+90}(t) &= A_2\left[A_1\cos(\theta)\sin(\omega t+\varphi+90^\circ) - B_1\sin(\theta)\cos(\omega t+\varphi+90^\circ)\right] \\ &= A_2\left[A_1\cos(\theta)\cos(\omega t+\varphi) + B_1\sin(\theta)\sin(\omega t+\varphi)\right] \qquad (13) \end{aligned}$$

Then from equations (12) and (13), the antenna output signal $v_{rcv}(t)$ in Figure 3 is:

$$v_{rcv}(t) = v_{x+90}(t) + v_y(t) = K_C\cos(\omega t+\varphi) + K_S\sin(\omega t+\varphi) \qquad (14)$$

where, for convenience, the non-time varying terms are grouped into two constants $K_C$ and $K_S$ as follows:

$$K_C = \left[B_1B_2 + A_1A_2\right]\cos(\theta) \qquad (15)$$

$$K_S = \left[A_1B_2 + B_1A_2\right]\sin(\theta) \qquad (16)$$

Since we have set the transmitted signal power Ps of s(t) equal to 1 (equation (3)) and the receive antenna gain to unity (equation (8)), then the time-averaged output signal power Prcv in Figure 3 represents the polarization mismatch loss or antenna coupling efficiency. A value of 1 indicates no polarization mismatch loss, while Prcv = 0 indicates infinite polarization isolation between the two antennas.

Let F denote the coupling efficiency between the two antennas. Then:

$$F = \mathrm{Prcv} = \lim_{T\to\infty} 1/T \int_{-T/2}^{T/2} v_{rcv}^2(t)\,dt = \lim_{T\to\infty} 1/T \int_{-T/2}^{T/2} \left[K_C\cos(\omega t+\varphi) + K_S\sin(\omega t+\varphi)\right]^2 dt$$

$$= \left[K_C^2 + K_S^2\right]/2 \qquad (17)$$

Substituting expressions for $K_C$ and $K_S$ from equations (15) and (16) yields:

$$F = (1/2)\left[\,(B_1B_2 + A_1A_2)^2\cos^2(\theta) + (A_1B_2 + B_1A_2)^2\sin^2(\theta)\,\right]$$

$$= (1/2)\left\{\,2A_1A_2B_1B_2\left[\cos^2(\theta) + \sin^2(\theta)\right] + \cos^2(\theta)(A_1^2A_2^2 + B_1^2B_2^2) + \sin^2(\theta)(A_1^2B_2^2 + B_1^2A_2^2)\,\right\} \qquad (18)$$

We now make the following trigonometric substitutions:

$$\cos^2(\theta) + \sin^2(\theta) = 1 \qquad (19)$$

$$\cos^2(\theta) = (1/2)\left[\,1 + \cos(2\theta)\,\right] \qquad (20)$$

$$\sin^2(\theta) = (1/2)\left[\,1 - \cos(2\theta)\,\right] \qquad (21)$$

Substituting equations (19), (20), and (21) into (18), and rearranging terms yields:

$$F = (1/4)\left[\,4A_1A_2B_1B_2 + A_1^2A_2^2 + B_1^2B_2^2 + A_1^2B_2^2 + B_1^2A_2^2 + \cos(2\theta)\,(A_1^2A_2^2 + B_1^2B_2^2 - A_1^2B_2^2 - B_1^2A_2^2)\,\right] \qquad (22)$$

Finally, substituting the expressions for $A_1$, $A_2$, $B_1$, and $B_2$ from equations (4), (5), (9), and (10), into (22) and simplifying gives the final expression for coupling efficiency F in terms of axial ratios $r_1$ and $r_2$, and the angle $\theta$ between the 2 antenna major axes:

$$F = \frac{4r_1r_2 + (r_1^2+1)(r_2^2+1) + (1-r_1^2)(1-r_2^2)\cos(2\theta)}{2\,(r_1^2+1)\,(r_2^2+1)} \qquad \text{(same sense pol.)} \qquad (23)$$

Recall that both antennas #1 and #2 were defined as having right-hand polarization sense. Therefore, equation (23) is valid for same-sense polarization. To determine the corresponding expression for opposite-sense polarization, either the input signal s(t) or receive antenna #2 can be redefined as having left-hand polarization sense. For example, the expression for s(t) from equation (2) now becomes:

$$s(t) = -A_1 \sin(\omega t + \varphi)\underline{\underline{x}} + B_1 \cos(\omega t + \varphi)\underline{\underline{y}} \qquad \text{(left-hand sense)} \qquad (24)$$

Alternatively, the receive antenna in Figure 2 can be converted to left-hand polarization sense by changing the phase shift of the major axis component from +90° to -90°. The expression for antenna coupling efficiency F was thus re-derived for the opposite-sense case using the same steps as described above for the same-sense derivation. The resulting expression for F was found to be identical to equation (23) except that the "$4r_1r_2$" term in the numerator becomes subtractive rather than additive.

The preceding results lead to the following general expression for F that can be used for both same and opposite polarization sense:

$$F = \frac{4Kr_1r_2 + (r_1^2+1)(r_2^2+1) + (1-r_1^2)(1-r_2^2)\cos(2\theta)}{2(r_1^2+1)(r_2^2+1)} \qquad (25)$$

where:

- $F$ = coupling efficiency.
- $r_1$ = antenna #1 voltage axial ratio $(1 \le r_1 \le \infty)$.
- $r_2$ = antenna #2 voltage axial ratio $(1 \le r_2 \le \infty)$.
- $\theta$ = angle between major axes of the 2 antennas.
- $K$ = 1 for same-sense polarization, = -1 for opposite sense.

**Some Cases of Interest:**
Using equation (25), Table A1 below shows the polarization mismatch loss for several specific polarization scenarios of interest:

**Table A1: Polarization Mismatch Loss for Specific Antenna Configurations**

| Scenario | $r_1$ | $r_2$ | $\theta$ | Sense | Pol. Loss (dB) |
|---|---|---|---|---|---|
| Linear Linear | $\infty$ | $\infty$ | $\theta$-variable | N/A | $20\log[\cos(\theta)]$ |
| Linear Circular | $\infty$ | 1 | N/A | N/A | -3.0 |
| Elliptical Linear | 4 (6 dB) | $\infty$ | 90° | N/A | -12.3 |
| Elliptical Elliptical | 1 dB | 3 dB | 45° | **opposite** | **-9.6** |